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# Error analysis of the rough model of the symmetric dual-optical signal detection based MOCT

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**Abstract**

Symmetric double signal analysis based magneto optical current transformer(MOCT) is usually based on a rough model to calculate the primary current, but due to the use of approximate calculation, the primary current and output voltage is not as strictly linear relationship, so the rough model introduce some errors，which exceed the national standard national electronic current transformer Standards 0.2 or 0.5 class accuracy requirements when the primary current increase outside a certain range, at this time the rough model can not be used to measure the current. As the voltage RMS and current RMS usually are used in the power system measurement , this article will analyze relationship between the actual output voltage RMS and the current RMS and obtain the relationship of the approximate calculation caused error and the increasing current RMS, and obtain the current measurement range that meet the accuracy requirement of the national standard.

*Keywords*: MOCT; rough model; approximate calculation; error analysis; current measurement range

## I Introduction

With the development and application of the electric power technology, power system put a higher requirement for equipment in small size, digital progress, and high reliability. Traditional electromagnetic current transformer (TA) due to saturation, transient performance and other issues, has been difficult to meet the development needs of the new generation power system online monitoring, high precision of disputes, and the power digital network. A new generation of optical current transformer which use the optical device based on Faraday magnetic rotation as current sensor came into being. As new electronic optical transformer being with low cost, high security, high precision, wide measurement range, etc., it has become the industry consensus that the new electronic optical transformer would supersede the conventional ferromagnetic transformer. This paper will focuse on the research of the magneto-optical current transducer (MOCT). MOCT has the advantage of better linearity, higher sensitivity, and good insulation properties. As a result of the existing MOCT model use approximate calculation, the model is not precise enough, that make its use has been limited . Through precise modeling and error analysis of the magneto-optical current transformer, this paper will obtain the influence factors and measurement range of the current measurement.

## II The Principle Of MOCT

The current measurement principle of the MOCT mainly use Faraday magnetic rotation effect. Faraday magnetic rotation effect means that in the optical isotropic transparent magneto-optical materials, the external magnetic field could make the polarization plane of linearly polarized light which spread parallel the magnetic field direction in the magneto-optical materials rotate[2]. MOCT uses Faraday effect to measure the current through the current-carrying conductor. The specific process is as follows: light beam emitted by the light source become linearly polarized light after passing polarizer and then come into the sensing head of the magnetic optical materials. Linearly polarized light circle the current-carrying conductor one week in the magneto-optical materials and its polarization plane will rotate with the effect of the magnetic field. So the current through the current-carrying conductor could be got by measuring the rotation angle $\theta$ of polarization plane in the analyzer, as shown in Fig. 1.


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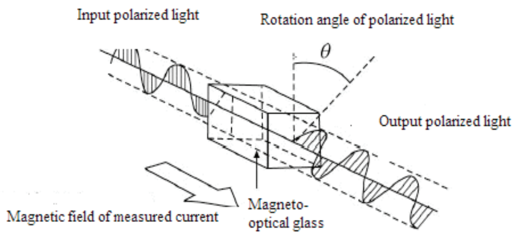


Fig. 1 Faraday effect schematic diagram

According to Faraday effect, the relationship between the rotation angle $\theta$ of the polarization plane and the current $i$ in the current-carrying conductor is as follows:

$$\theta = V \oint \vec{H} \cdot d\vec{l} = VNi \qquad (1)$$

$V$ is the Verdet constant of magnetic optical materials. $H$ is the magnetic field strength which is generated by the primary side current $i$ in the optical path. $l$ is the optical path in the magnetic optical materials. When the light beam circle around the current-carrying conductor one week, $N = 1$.The part of integral in (1) is only related to the current $i$ and the relative position between the light path and the current-carrying conductor. The current in the current-carrying conductor could be got by measuring the size of $\theta$.

The light in the optical glass after passing polarizer is $J_0$, the output light intensity in polarizer is $J$, according to Malus law[3]:

$$J = aJ_0 \cos^2(\theta + \gamma) \qquad (2)$$

In (2), $a$ is the intensity attenuation coefficient of the light path; $\gamma$ is the optical axis intersecting angle of polarizer and the analyzer. $\theta$ has the maximum sensitivity when $\gamma = \pi / 4$. (2) change to be:

$$J = aJ_0 \cos^2(\theta + \frac{\pi}{4}) = aJ_0(1 - \sin 2\theta)/2 \qquad (3)$$

when $\theta$ is small, $\sin 2\theta \approx 2\theta$, (3) could be changed as:

$$J \approx aJ_0(1-2\theta)/2 = aJ_0(1-2Vi)/2 \qquad (4)$$

## III Signal Processing Circuit

Converter of the electronic converter transformer can transform the optical signal of the measured current into electric signal. Nowadays, dual optical path method is used too much to transform the optical signal into electrical signal of the current in current-carrying conductor[5]. The method is using the Wollaston prism or a polarizing beam splitter as the output polarizer to divide polarized light into two beams (Fig.2), then using the photoelectric detector and signal processing circuit for conversion, process of the light signal and obtaining the value of $\theta$ that include the information of the measured current, so could obtain the primary current.

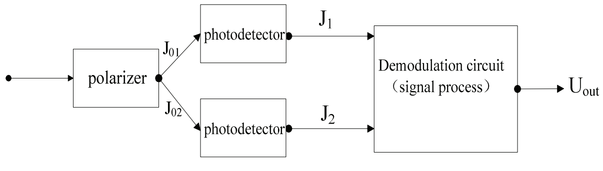


Fig.2 Dual optical signal process circuit

The specific implementation process is as follows: two light output of optical signal are probed by two photoelectric detectors; then make the subtraction of the two electrical signals divided by their sum and get the relationship of the output voltage and conductor current, as shown in the following formula.

$$u_{out} = \frac{J_1 - J_2}{J_1 + J_2} \quad (5)$$

$J_1, J_2$ expressions are (6) and (7):

$$J_1 = a_1 \frac{1}{2} J_{01}(1 - \sin 2\theta) + n_1(t) \quad (6)$$

$$J_2 = a_2 \frac{1}{2} J_{02}(1 + \sin 2\theta) + n_2(t) \quad (7)$$

Substituting (6) and (7) into (5):

$$u_{out} = \frac{a_1 \frac{1}{2} J_{01}(1-\sin 2\theta) - a_2 \frac{1}{2} J_{02}(1+\sin 2\theta) + [n_1(t) - n_2(t)]}{a_1 \frac{1}{2} J_{01}(1-\sin 2\theta) + a_2 \frac{1}{2} J_{02}(1+\sin 2\theta) + [n_1(t) + n_2(t)]} \quad (8)$$

In the ideal state, $a_1 = a_2 = a$ , $J_{01}=J_{02}=J_0$ and $n_1(t) = n_2(t) << 1$, the additive noise in every electrical signal, an precise model equation could be obtained as:

$$u_{out} = \frac{-aJ_0 \sin(2Vi)}{aJ_0} = -\sin(2Vi) \quad (9)$$

When $\theta$ is very small, (9) could be changed into an approximate model as:

$$u_{out} = -\sin(2Vi) \approx -2Vi \quad (10)$$

Equation (10) is the expression of the output signal in the ideal state.

## IV Error Analysis Of The Rough Model

The existing magneto-optical current transformer is usually based on a rough model to calculate the primary current, which greatly simplifies the model and calculation, but using the approximate calculation cause the current and output voltage is not as strictly linear relationship, so with this type calculation introduce a number of errors. This paper will analyze the relationship between the current RMS and voltage RMS of the two models to obtain the error. The power system frequency is 50HZ, Suppose $i = \sqrt{2} I_p \sin(\omega t)$ ,the approximate output voltage RMS of the rough model is $U$ , the actual output voltage RMS of the accurate model is $U_0$, the error is $\varepsilon$ , then

The output voltage of the rough model is

$$u = -2Vi = -2\sqrt{2} V I_p \sin(\omega t) \quad (11)$$

The approximate voltage RMS is

$$U = 2VI_p \quad (12)$$

The output voltage of the accurate model is

$$u_0 = -\sin(2Vi) = -\sin[2\sqrt{2} V I_p \sin(\omega t)] \quad (13)$$

The actual voltage RMS is

$$U_0 = \sqrt{\frac{1}{T}\int_0^T u^2 dt} = \sqrt{\frac{1}{T}\int_0^T (\sin(2Vi))^2 dt} = \sqrt{\frac{1}{0.02}\int_0^{0.02} (\sin(2V \cdot \sqrt{2} I_p \sin(2 \cdot \pi \cdot 50 \cdot t))^2 dt} \quad (14)$$

So the error can be expressed as

$$\varepsilon = \left| \frac{U - U_0}{U} \right| \times 100\% \qquad (15)$$

From (15) we can see that the error caused by the approximate calculation relate to the primary current RMS. Though MATLAB simulation , this paper will get the error curve with the current change and the current measurement range meet the national electronic current transformer Standards 0.2 and 0.5 class accuracy requirements of the rough model .

## V MATLAB SIMULATION

This article select the anti-magnetic ZF-7 optical glass as the sensor head materials, and the laser of working center wavelength $\lambda = 850$nm as light source (the wavelength error range is less than 5nm, operating temperature is -25 ~ 60 ° C, the output power is not less than 2mw). At this point V = 1.405349951 rad / A[6]. The relationship between the approximate and the actual voltage RMS with the current changes can be obtained through the MATLAB simulation , as shown in Fig. 3.

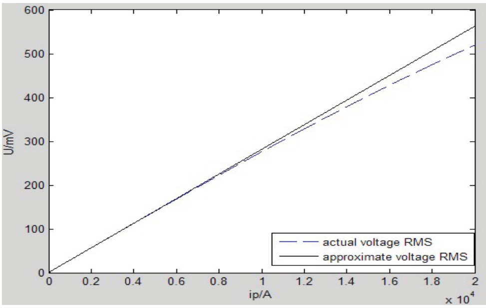


Fig. 3 The approximate and the actual voltage curve with the current change

It can be seen from Fig.3 that , when the current RMS is small, the approximate output voltage U is very close to the actual output voltage $U_0$ , it can be regarded as almost equal between the two, but when the primary current RMS increases, both the gap between the two and the error grow, which exceed the national standard. This time the rough model should not be used for measuring the current. Fig.4 shows the error curve with the current.

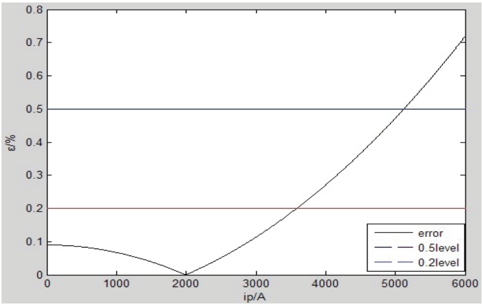


Fig.4 Error curve

Fig.4 shows, within a current certain range, the error is small, the rough model can be used to obtain the current value. But once the current exceeds a certain range, the error increases far beyond the accuracy requirements of national standards as the current increases. Table 1 shows the detailed data.

Table 1 Detailed data

| $I_p$/A | ε /% | $U_0$/mv | U/mv | $I_p$/A | ε /% | $U_0$/mv | U/mv |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 3000 | 0.112574 | 84.226073 | 84.320997 |
| 300 | 0.088057 | 8.439525 | 8.432100 | 3300 | 0.155094 | 92.609242 | 92.753097 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 600 | 0.081973 | 16.878024 | 16.864199 | 3600 | 0.201648 | 100.981159 | 101.185196 |
| 900 | 0.071834 | 25.314470 | 25.296299 | 3900 | 0.252231 | 109.340807 | 109.617296 |
| 1200 | 0.057639 | 33.747840 | 33.728399 | 4200 | 0.306840 | 117.687173 | 118.049396 |
| 1500 | 0.039392 | 42.177106 | 42.160499 | 4500 | 0.365469 | 126.019245 | 126.481496 |
| 1800 | 0.017093 | 50.601246 | 50.592598 | 4800 | 0.428113 | 134.336012 | 134.913595 |
| 2100 | 0.009256 | 59.019235 | 59.024698 | 5100 | 0.494767 | 142.636468 | 143.345695 |
| 2400 | 0.039652 | 67.430050 | 67.456798 | 5400 | 0.565424 | 150.919607 | 151.777795 |
| 2700 | 0.074092 | 75.832669 | 75.888897 | 5700 | 0.640078 | 159.184427 | 160.209894 |

As showing in Table 1, when $I_p$ is more than 3600A, the error caused by the rough model is more than 0.2 accuracy requirements of national standards, when $I_p$ is more than 5100A, then the error caused by the rough model is more than 0.5 accuracy requirements of national standards . The simulation results indicate that when the primary current exceed over the measurement range, the measurement results of the rough model will be greatly distorted far beyond the measuring accuracy of optical transformers. When the current turn larger caused by the power system fault, the current measurement of a rough model will deviate from the actual value, resulting in measurement error, then an accurate model should be used to calculate the current value rather than the rough one.

## VI Conclusion

Through MOCT theoretical modeling and simulation analysis, this paper obtain that ,the symmetry dual optical signals-based optical current transformer using rough model to measure the primary current, introduce a number of errors. When the primary current is large, the error increase large more and more with the current , so the rough model can only measure the current within a certain range, when the primary current exceeds the range, error caused by the approximate calculation will exceed the national electronic current transformer Standards 0.2 or 0.5 class accuracy requirements . Meanwhile, the magneto-optical materials, the laps that the optical path circle around the conductor, the Verdet constant of the optical materials and different signal processing methods also affect the size of the error, thereby changing the primary current measurement ranges. Researchers and designers working in the MOCT field should be according to the actual situation, select the appropriate individual parameters.

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